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STATISTICAL ANALYSIS OF RUTTING BEHAVIOR OF HMA MIX DESIGNS

FINAL REPORT

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16. Abstract

This report has presents an analysis of laboratory and field rutting performance for a variety of Stone Matrix Asphalt (SMA) and WisDOT standard Hot Mix Asphalt (HMA) mix designs constructed throughout the State of Wisconsin. Laboratory testing using the Georgia Loaded Wheel Tester was conducted on specimens compacted in the lab as well as on specimens cut from the surface of the constructed pavements. Field rut measurements were taken at yearly intervals between 1995 and 1998 using two configurations of the WisDOT profiler.

Relative rankings of the various mix designs, in terms of rut resistance, were developed based on measured rut accumulations in the lab (lab prepared and field obtained specimens) as well from field rut measurements. Significant variations in lab and field performance were noted, producing inconsistent rankings for many of the mix designs.

Based on field rutting data collected in Southern Wisconsin, mix designs incorporating the larger maximum aggreagte size (16 mm vs. 10 mm) are providing better long-term rutting resistance. Furthermore, the SMA mix designs investigated are not providing increased long-term rut resistance as compared to the standard WisDOT HV3 mix design.

17. Key Words Hot Mix Asphalt, Stone Matrix Asphalt, Rutting Resistance, Pavement Performance	18. Distribution Statement		
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STATISTICAL ANALYSIS OF RUTTING BEHAVIOR OF HMA MIX DESIGNS

FINAL REPORT WI/SPR-09-99
WisDOT Highway Research Study #94-16
SPR # 0092-45-69

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1.0 INTRODUCTION

This report provides a review and analysis of laboratory and field rutting data from a variety of Hot Mix Asphalt (HMA) designs constructed throughout the State of Wisconsin. The primary objectives of this analysis were 1) to provide the Wisconsin Department of Transportation (WisDOT) with a statistical comparison of field performance of the various mix designs, based on measured rutting imposed by accumulated traffic loads, and 2) to develop correlations between laboratory rut test data and mix performance under variable design traffic levels.

1.1 Project Locations

Twelve paving projects, located throughout the State of Wisconsin, were included in this research. Figure 1-1 illustrates the locations of the research projects. Table 1-1 provides a summary of the project locations. HMA mix designs include the standard WisDOT HV3 (Control) and MV3 mixes as well as stabilized HV3 mixes and a variety of Strategic Highway Research Program (SHRP) and Stone Mastic Asphalt (SMA) designs. Table 1-2 provides descriptions of the test section codes used in this report.

1.2 Laboratory Testing Program

Laboratory testing was conducted using the Georgia Loaded Wheel Tester (GaLWT). Tests were conducted on HMA specimens produced in the laboratory, using mix designs and materials for each project, as well as on field specimens extracted from completed paving projects throughout the State of Wisconsin.

1.3 Field Rutting Measurements

Field rutting data were collected using the Wisconsin Department of Transportation (WisDOT) road profiler. Data was collected during the months of September and October from 1995 to 1998.

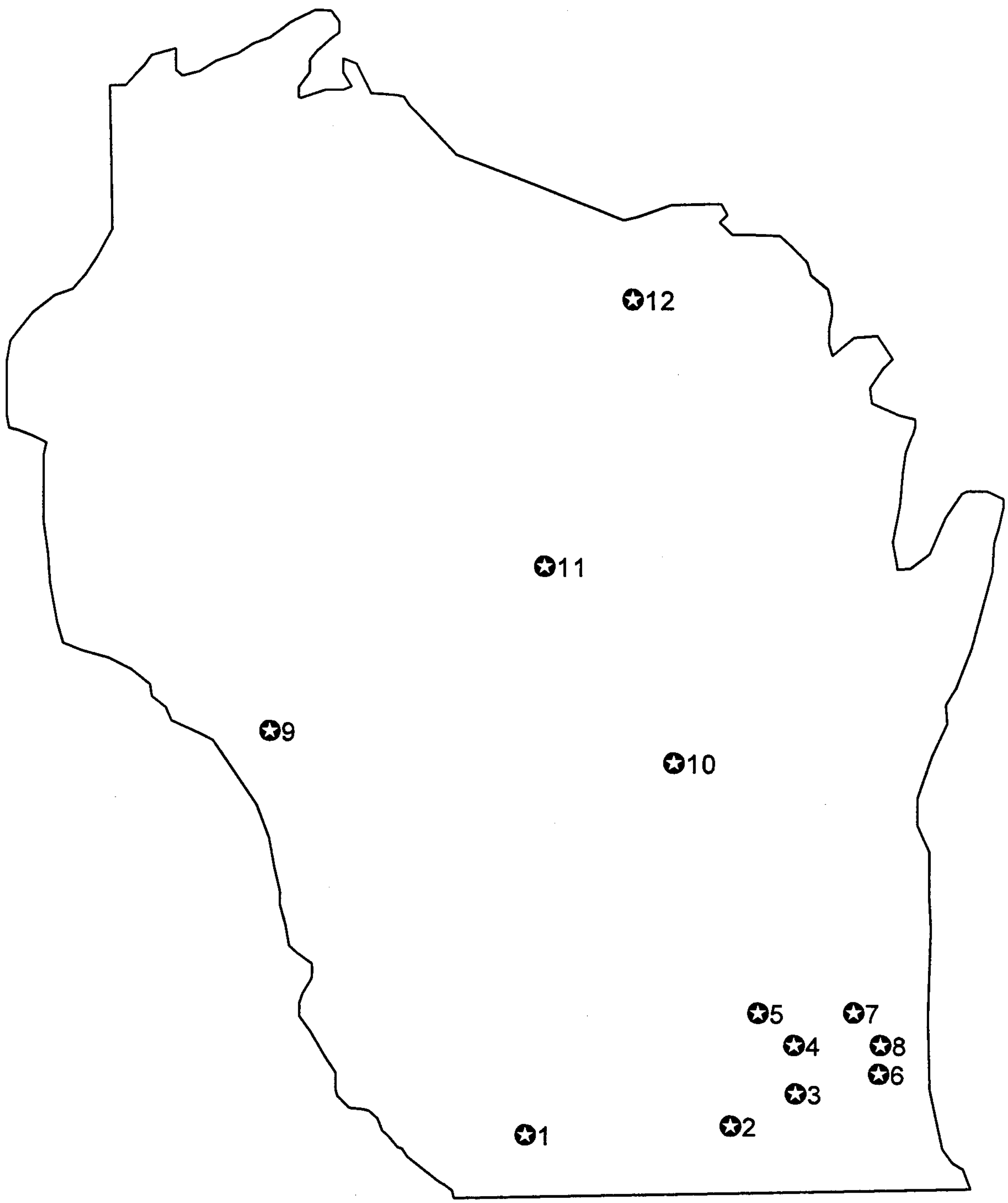


Figure 1-1: Project Locations

Table 1-1: Project Descriptions

Map Code (1)	Project Location	Project Limits	Mix Types	Placement Date
1	USH 151 Grant/Lafayette Co.	Platteville to Belmont	HV3, F1, F2, P1, P2, E1, E2	9/93
2	I-43 Walworth Co.	USH 20 to STH 120	HV3, F1, F2, E1, E2 P1, P2, HV3-MAC10	8/93
3	I-43 Waukesha Co.	STH 164 to CTH Y	HV3, MAC10, F1, F2, P1, SHRP-X	8/93
4	I-94 Waukesha Co.	Dousman Rd to CTH BB	SMA(E), A3	Summer 92
5	STH 67 Waukesha Co.	CTH B to Lexington Drive	HV3	8/94
6	STH 100 Milwaukee Co.	13th St to 27th ST (USH 41)	SMA	9/93
7	I-894 Milwaukee Co.	Zoo - Hale Interchanges	SMA	9/94
8	I-43/894 Milwaukee Co.	Hale - Mitchell Interchanges	SMA	9/94
9	USH 53 Trempealeau Co.	Whitehall to Pigeon Falls	MV3	9/95
10	STH 73 Columbia Co.	Crawfish River to REC Road	MV3	9/93
11	USH 51 Portage/Marathon Co.	Bus 51 to STH 34	HV3	9/93
12	USH 45 Oneida/Vilas Co.	Eagle River to Three Lakes	HV3, F1, F2, P1, P2, E1, E2, E2M	10/93

(1) Map codes illustrated on Figure 1-1

Table 1-2: Description of In-Place Test Sections

Test Section Code	Mix Design Description
HV3	WisDOT standard dense graded high volume mix (Control)
MV3	WisDOT standard dense graded medium volume mix
SMA	Standard SMA mix with no additives
SMA - F1	SMA with 0.3% organic fibers
SMA - F2	SMA with 0.5% inorganic fibers
SMA - E1	SMA with 3% MAC 10 elastomeric polymer
SMA - E2	SMA with 5% MAC 10 elastomeric polymer
SMA - P1	SMA with 5% Vestoplast polymer
SMA - P2	SMA with 7% Vestoplast polymer
SHRP-MAC10	SHRP mix design with 3% MAC10 elastomeric polymer
SHRP-X	SHRP mix design - no polymers
HV3-MAC10	WisDOT HV3 mix with 3% MAC10 elastomeric polymer
A3	Previous WisDOT standard dense graded high volume mix
SMA(E)	Original European design SMA mix

2.0 TRAFFIC ANALYSIS

Traffic information for the pavement sections included in this study was obtained from pavement design reports prepared for each project. This information was analyzed to determine yearly accumulations of Equivalent Single Axle Loads (ESALs) for each project site. Information utilized for this analysis includes:

1. Construction Year / ADT
2. Design Year / ADT
3. Directional Factor
4. Lane Distribution Factor
5. Truck Traffic Distribution

The average annual traffic growth rate was determined based on the specified construction year and design year ADT values using the equation:

$$g = \left(\frac{DYADT}{CYADT} \right)^{\frac{1}{N}} - 1$$

where: g = average annual growth rate, decimal value

DYADT = Design Year ADT

CYADT = Construction Year ADT

N = design years, typically N = 20

Construction year total ESAL values within the design lane were determined using the equation:

$$CYDLESAL = \left[\sum T_i \times TF_i \right] \times CYADT \times DF \times LDF \times 365$$

where: CYDLESAL = total construction year design lane ESALs

T_i = % of ADT for truck classification i, decimal value

TF_i = WisDOT truck factor for truck classification i

DF = direction factor

LDF = lane distribution factor

The total design lane ESAL values in any year are determined by multiplying the previous year total design lane ESAL value by $(1+g)$. Cumulative design lane ESAL values for any year are determined as the simple summation of previous years ESAL values. Table 2-1 provides an example of this calculation process. It should be noted that the total 20-year cumulative design lane ESAL values calculated by the above process will yield a result which is lower than the 20-year total design lane ESAL values calculated by the standard WisDOT analysis procedures for any $g > 0$. This discrepancy increases as g increases.

The cumulative design lane ESAL values at the time of field rutting measurements at each project site were determined based on the construction year used for the ESAL calculations, the actual year the project was constructed, and the year of the field survey. For example, if the example pavement described in Table 2-1 was actually constructed in 1994, the total accumulated ESALs at the time of a September 1995 field survey would be assumed equal to 52,972 (Year 1995 design lane ESALs). Table 2-2 provides the placement dates and estimated cumulative ESAL values for each project site at the time of the 1995, 1996, 1997 and 1998 field surveys.

Table 2-1: Example ESAL Calculations

Construction Year / ADT 1993 / 4100	Design Year / ADT 2013 / 5000	Directional Factor DF = 0.5	Lane Distribution Factor LDF = 1.0
Annual Growth Rate, g = $[5000 / 4100]^{0.05} - 1 = 0.01$			
Truck Type	% of ADT, Ti	Truck Factor, TFi	ESAL
2D	0.044	0.3	0.0132
3-SU	0.006	0.8	0.0048
2S-1, 2S-2	0.027	0.5	0.0135
3S-2	0.031	0.9	0.0279
DBL BTM	0.005	2.0	0.0100
		$\sum$ Ti x TFi =	0.0694
CYDLESAL = [$\sum$Ti x TFi] x CYADT x LDF x DF x 365 = 0.0694 x 4100 x 0.5 x 1.0 x 365 = 51,928			

Year	Yearly Design Lane ESALs	Cumulative Design Lane ESALs
1993	51,928	51,928
1994	52,447	104,375
1995	52,972	157,347
1996	53,501	210,849
1997	54,036	264,885
1998	54,577	319,462
1999	55,123	374,584
2000	55,674	430,258
2001	56,231	486,489
2002	56,793	543,282
2003	57,361	600,643
2004	57,934	658,577
2005	58,514	717,091
2006	59,099	776,190
2007	59,690	835,880
2008	60,287	896,166
2009	60,890	957,056
2010	61,499	1,018,555
2011	62,114	1,080,668
2012	62,735	1,143,403

Table 2-2: Estimated Cumulative ESAL Values

Project Location	Mix Types	Growth Rate (g)	Placement Date	1995 ESALs	1996 ESALs	1997 ESALs	1998 ESALs
I-43 (NB) Walworth Co.	HV3, F1, F2, P1, P2	0.038	8/93	675,854	1,032,899	1,403,329	1,787,645
I-43 (SB) Walworth Co.	HV3, E1, E2, SHRP MAC10	0.038	8/93	675,854	1,032,899	1,403,329	1,787,645
USH 151 Grant/Lafayette Co.	HV3, F1, F2, P1, P2, E1, E2	0.014	9/93	194,898	294,387	395,262	497,541
USH 45 (NB) Oneida/Vilas Co.	HV3, F1, F2, P1, P2, E1, E2, E2M	0.014	10/93	77,394	116,903	156,964	197,585
USH 45 (SB) Oneida/Vilas Co.	HV3, F1, F2, P1, P2, E1, E2, E2M	0.014	10/93	134,794	202,648	271,427	341,146
USH 51 Portage/Marathon Co.	HV3	0.009	9/93	517,379	779,711	1,044,502	1,311,774
STH 67 Waukesha Co.	HV3	0.014	8/94	71,227	143,474	216,755	291,085
STH 100 Milwaukee Co.	SMA	0.019	9/93	820,302	1,104,142	1,393,350	1,688,028
I-894 Milwaukee Co. Zoo - Hale Interchanges	SMA	0.014	9/94	1,455,807	2,188,782	2,932,045	3,685,738
I-43/894 Milwaukee Co. Hale - Mitchell Interchanges	SMA	0.012	9/94	777,024	1,563,424	2,359,313	3,164,806
STH 53 Trempealeau Co.	MV3	0.010	9/95	4,260	51,929	104,375	157,344
I-43 Waukesha Co.	HV3, SHRP MAC10, F1, F2, P1, P2, E1, E2, SHRP-X	0.038	8/93	1,520,672	2,324,023	3,157,490	4,022,201
I-94 Waukesha Co.	SMA(E), A3	0.017	Summer 92	1,744,427	2,111,374	2,484,583	2,864,161
STH 73 Columbia Co.	MV3	0.013	9/93	60,986	122,899	185,753	249,562

3.0 LABORATORY RUTTING ANALYSIS

Laboratory testing, using the Georgia Loaded Wheel Tester (GaLWT), was primarily conducted in 1994. Tests were conducted on lab prepared specimens, using mix designs established for each project, and on specimens extracted from completed paving projects. Not all mixes were included in the GaLWT testing program. Table 3-1 provides a summary of the GaLWT test results for the mixes tested. Details of the test method and lab results are provided in the June 1996 project report entitled "Comparison and Statistical Analysis of Field Rutting Measurement with Laboratory Predictive Methods."

Table 3-1: GaLWT Test Summary

Project Location	Mix Type	Mix ID	GaLWT Laboratory Test Data			
			Lab Prepared Specimens [1]		Field Obtained Specimens [2]	
			1000 Reps	8000 Reps	1000 Reps	8000 Reps
I-43 (NB) Walworth Co.	SMA-F1	F1-43L	0.110	0.174	0.180	0.358
	SMA-P1	P1-43L	0.120	0.215	0.104	0.232
	SMA-F2	F2-I43	0.131	0.197	0.098	0.168
I-43 (SB) Walworth Co.	SMA-E2	E2-43L	0.167	0.319	0.069	0.104
	HV3	HV3-43L	0.214	0.426	0.107	0.342
USH 151 Grant/Lafayette Co.	SMA-F1	F1-151-S	0.094	0.173	0.114	0.243
	SMA-F2	F2-151	0.127	0.243	0.157	0.253
	SMA-E1	E1-151	0.141	0.227	0.155	0.216
	SMA-E2	E2-151	n.a.[3]	n.a.	n.a.	n.a.
	SMA-P1	P1-151	0.112	0.172	0.100	0.181
	SMA-P2	P2-151	0.093	0.146	0.086	0.199
	HV3	HV3-151	0.182	n.a.	0.334	n.a.
US 51 (NB) Portage/Marathon Co.	HV3	HV3-51	0.173	0.516	0.102	0.222

(1) Specimens prepared in the lab using project mix designs and materials.
(2) Specimens extracted from the field after paving.
(3) No specimens obtained and no GaLWT testing conducted for this mix.

Table 3-1: GaLWT Test Summary (Cont.)

Project Location	Mix Type	Mix ID	GaLWT Laboratory Test Data			
			Lab Prepared Specimens (1)		Field Obtained Specimens (2)	
			1000 Reps	8000 Reps	1000 Reps	8000 Reps
I-94 Waukesha Co.	A3	2-F-91	0.124	0.344	n.a.(3)	n.a.
	SMA(E)		n.a.	n.a.	n.a.	n.a.
STH 67 Waukesha Co.	HV3	12-F-93	0.124	0.269	n.a.	n.a.
STH 100 Milwaukee Co.	SMA	126-F-92	0.066	0.108	n.a.	n.a.
STH 73 Columbia Co.	MV3	180-F-93	0.173	0.359	n.a.	n.a.
USH 45 Oneida/Vilas Co.	HV3	199-F-93	0.177	0.294	n.a.	n.a.
	SMA-F1	206-F-93	0.118	0.178	n.a.	n.a.
	SMA-F2	207-F-93	0.122	0.204	n.a.	n.a.
	SMA-P1	208-F-93	0.129	0.227	n.a.	n.a.
	SMA-P2	209-F-93	0.100	0.143	n.a.	n.a.
	SMA-E1	210-F-93	0.104	0.157	n.a.	n.a.
	SMA-E2, SMA-E2M	211-F-93	0.103	0.134	n.a.	n.a.

(1) Specimens prepared in the lab using project mix designs and materials.
(2) Specimens extracted from the field after paving.
(3) No specimens obtained and no GaLWT testing conducted for this mix.

Table 3-1: GaLWT Test Summary (Cont.)

Project Location	Mix Type	Mix ID	GaLWT Laboratory Test Data			
			Lab Prepared Specimens [1]		Field Obtained Specimens [2]	
			1000 Reps	8000 Reps	1000 Reps	8000 Reps
I-894 Milwaukee Co. Zoo-Hale Interchanges	SMA	59-F-94	0.150	0.320	n.a.[3]	n.a.
I-43/894 Milwaukee Co. Hale-Mitchell Interchanges	SMA	56-F-94	0.080	0.130	n.a.	n.a.
STH 53 Trempealeau Co.	MV3	STH 53	n.a.	n.a.	n.a.	n.a.
I-43 Waukesha Co.	HV3	n.a.	n.a.	n.a.	n.a.	n.a.
	MAC10	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-F1	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-F2	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-P1	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-P2	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-E1	n.a.	n.a.	n.a.	n.a.	n.a.
	SMA-E2	n.a.	n.a.	n.a.	n.a.	n.a.
	SHRP-X	n.a.	n.a.	n.a.	n.a.	n.a.

(1) Specimens prepared in the lab using project mix designs and materials.
(2) Specimens extracted from the field after paving.
(3) No specimens obtained and no GaLWT testing conducted for this mix.

4.0 FIELD PERFORMANCE TESTING

Field surveys were conducted during the months of September and October from 1995 to 1998 to establish average rut depths in the right wheel path of each test section. The WisDOT road profiler was utilized for all data collection. During the 1995 survey, the profiler was equipped with three sensors for measuring the rut depth in the right wheel path. During subsequent 1996-1998 surveys, the WisDOT road profiler was upgraded to include six sensors for measuring rutting the in right wheel path. Figure 4-1 illustrates the two sensor configurations and sensor spacings utilized for field rutting measurements.

Rut depths were calculated from 1995 survey data by subtracting the average of the outer sensor readings from the wheel track value. Rut depths were calculated from 1996-1998 survey data by subtracting the average of the outer sensor readings from the maximum reading of the four central sensors.

Rut depth measurements were made at one foot increments along each test section. These data were grouped into 100 foot sample increments and reported as average rut depths within each 100 foot sample. These sample averages were utilized to compute the overall average rut depths and the standard deviation of rut depth measurements within each test section. Due to variable test section lengths, the number of 100 foot sample increments was also preserved for use in the statistical analysis. Table 4-1 provides a summary of all collected field rutting data.

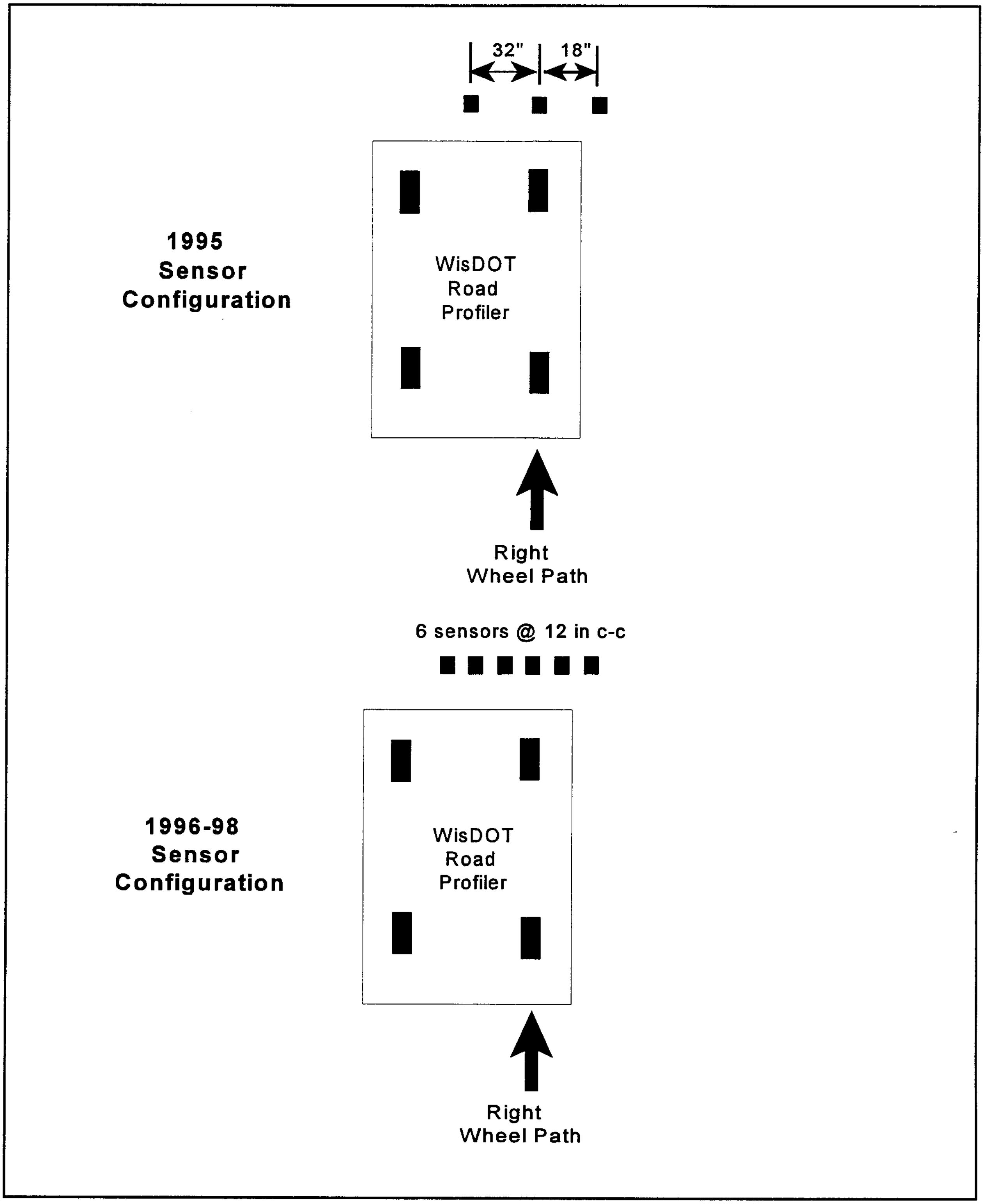


Figure 4-1: WisDOT Road Profiler Sensor Configurations

Table 4-1: Summary of Field Rutting Measurements

Project Location	Mix Type	1995				1996				1997				1998			
		ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)
I-43 (NB) Walworth Co.	SMA-F1	675,854	0.032	40	0.0141	1,032,899	0.095	40	0.0229	1,403,329	0.123	40	0.0185	1,787,645	0.067	50	0.0306
	SMA-P1	675,854	0.027	35	0.0109	1,032,899	0.076	35	0.0188	1,403,329	0.129	35	0.0311	1,787,645	0.104	61	0.0296
	SMA-F2	675,854	0.027	40	0.0145	1,032,899	0.075	40	0.0113	1,403,329	0.136	40	0.0167	1,787,645	0.070	49	0.0278
	SMA-P2	675,854	(4)	(4)	(4)	1,032,899	(4)	(4)	(4)	1,403,329	(4)	(4)	(4)	1,787,645	0.080	43	0.0303
	HV3	675,854	(4)	(4)	(4)	1,032,899	(4)	(4)	(4)	1,403,329	(4)	(4)	(4)	1,787,645	0.127	41	0.0240
I-43 (SB) Walworth Co.	SMA-E1	675,854	(4)	(4)	(4)	1,032,899	(4)	(4)	(4)	1,403,329	(4)	(4)	(4)	1,787,645	0.088	45	0.0153
	SMA-E2	675,854	0.058	40	0.0082	1,032,899	0.055	40	0.0106	1,403,329	0.100	40	0.0278	1,787,645	0.121	50	0.0232
	HV3	675,854	0.065	31	0.0126	1,032,899	0.048	31	0.0106	1,403,329	0.089	31	0.0134	1,787,645	0.099	40	0.0146
	HV-MAC10	675,854				1,032,899	(4)	(4)	(4)	1,403,329	(4)	(4)	(4)	1,787,645	0.063	19	0.0170
USH 151 Grant/Lafayette Co.	SMA-F1	194,898	0.056	49	0.0266	294,387	0.064	49	0.0404	395,262	0.127	49	0.0196	497,541	0.134	50	0.0906
	SMA-F2	194,898	0.054	40	0.0249	294,387	0.074	40	0.0375	395,262	0.115	40	0.0321	497,541	0.129	51	0.0643
	SMA-E1	194,898	0.058	38	0.0286	294,387	0.089	38	0.0460	395,262	0.111	38	0.0112	497,541	0.097	38	0.0434
	SMA-E2	194,898	0.046	39	0.0207	294,387	0.038	39	0.0230	395,262	0.125	38	0.0108	497,541	0.126	40	0.0443
	SMA-P1	194,898	0.063	44	0.0407	294,387	0.067	44	0.0397	395,262	0.104	44	0.0280	497,541	0.124	38	0.0563
	SMA-P2	194,898	0.055	45	0.0211	294,387	0.057	45	0.0371	395,262	0.110	45	0.0102	497,541	0.122	45	0.0704
	HV3	194,898	0.057	41	0.0290	294,387	0.051	40	0.0247	395,262	0.108	41	0.0117	497,541	0.065	40	0.0343
US 51 Portage/Marathon Co.	HV3	517,379	0.028	634	0.0166	779,711	0.209	634	0.0262	1,044,502	0.086	608	0.0230	1,311,774	(4)	(4)	(4)

(1) Overall average rut depth in right wheel path, inches.
(2) Number of reported 100 foot increments within test section.
(3) Standard deviation of rut depth measurements, inches.
(4) Rut depth data unavailable.

Table 4-1: Summary of Field Rutting Measurements (Cont.)

Project Location	Mix Type	1995				1996				1997				1998			
		ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)
I-94 Waukesha Co.	SMA(E)	1,744,427	0.087	30	0.0204	2,111,374	0.034	30	0.0140	2,484,583	0.196	29	0.0394	2,864,161	0.042	31	0.0119
	A3	1,744,427	0.065	4	0.0058	2,111,374	0.060	4	0.0000	2,484,583	0.105	2	0.0071	2,864,161	0.055	4	0.0058
STH 67 Waukesha Co.	HV3	71,227	0.086	71	0.0188	143,474	0.033	71	0.0150	216,755	0.154	71	0.0196	291,085	(4)	(4)	(4)
STH 100 Milwaukee Co.	SMA	820,302	0.065	51	0.0228	1,104,142	0.070	51	0.0216	1,393,350	0.093	51	0.0201	1,688,028	(4)	(4)	(4)
STH 73 Columbia Co	MV3-P	60,986	0.044	23	0.0147	122,899	0.076	23	0.0120	185,753	0.147	23	0.0285	249,562	0.033	24	0.0179
	MV3-R	60,986	0.024	24	0.0082	122,899	0.083	24	0.0210	185,753	0.155	24	0.0189	249,562	0.041	33	0.0240
USH 45 (NB) Oneida/Vilas Co.	HV3	77,394	0.080	86	0.0370	116,903	0.142	86	0.0668	156,964	0.062	86	0.0410	197,585	(4)	(4)	(4)
	SMA-F1	77,394	0.056	39	0.0316	116,903	0.130	39	0.0456	156,964	0.058	39	0.0215	197,585	(4)	(4)	(4)
	SMA-F2	77,394	0.131	37	0.0556	116,903	0.278	37	0.0985	156,964	0.102	37	0.0521	197,585	(4)	(4)	(4)
	SMA-P1	77,394	0.098	39	0.0682	116,903	0.226	39	0.1184	156,964	0.084	39	0.0367	197,585	(4)	(4)	(4)
	SMA-P2	77,394	0.092	39	0.0403	116,903	0.167	39	0.0706	156,964	0.077	39	0.0319	197,585	(4)	(4)	(4)
	SMA-E1	77,394	0.079	38	0.0392	116,903	0.250	38	0.0478	156,964	0.120	38	0.0982	197,585	(4)	(4)	(4)
	SMA-E2	77,394	0.105	38	0.0431	116,903	0.180	38	0.0750	156,964	0.096	38	0.0383	197,585	(4)	(4)	(4)
	SMA-E2M	77,394	0.081	42	0.0333	116,903	0.168	42	0.0255	156,964	0.087	42	0.0310	197,585	(4)	(4)	(4)

(1) Overall average rut depth in right wheel path, inches.
(2) Number of reported 100 foot increments within test section.
(3) Standard deviation of rut depth measurements, inches.
(4) Rut depth data unavailable.

Table 4-1: Summary of Field Rutting Measurements (Cont.)

Project Location	Mix Type	1995				1996				1997				1998			
		ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)
USH 45 (SB) Oneida/Vilas Co.	HV3	134,794	0.077	86	0.0455	202,648	0.240	86	0.0737	271,427	0.054	86	0.0223	341,146	(4)	(4)	(4)
	SMA-F1	134,794	0.072	39	0.0421	202,648	0.293	39	0.0519	271,427	0.068	39	0.0287	341,146	(4)	(4)	(4)
	SMA-F2	134,794	0.070	36	0.0410	202,648	0.251	36	0.0600	271,427	0.097	36	0.0580	341,146	(4)	(4)	(4)
	SMA-P1	134,794	0.093	39	0.0485	202,648	0.267	39	0.0591	271,427	0.074	39	0.0335	341,146	(4)	(4)	(4)
	SMA-P2	134,794	0.056	39	0.0299	202,648	0.246	39	0.0531	271,427	0.066	39	0.0204	341,146	(4)	(4)	(4)
	SMA-E1	134,794	0.098	39	0.0490	202,648	0.268	39	0.0712	271,427	0.114	39	0.0577	341,146	(4)	(4)	(4)
	SMA-E2	134,794	0.085	38	0.0484	202,648	0.251	38	0.0507	271,427	0.064	38	0.0244	341,146	(4)	(4)	(4)
	SMA-E2M	134,794	0.80	42	0.0332	202,648	0.153	42	0.0340	271,427	0.101	42	0.0218	341,146	(4)	(4)	(4)
I-894 Milwaukee Co. Zoo-Hale Interchanges	SMA	1,455,807	0.068	27	0.0219	2,188,782	0.078	27	0.0258	2,932,045	0.080	27	0.0429	3,685,738	(4)	(4)	(4)
I-43/894 Milwaukee Co. Hale-Mitchell Interchanges	SMA	777,024	0.062	65	0.232	1,563,424	0.106	65	0.0297	2,359,313	0.083	61	0.0188	3,164,806	(4)	(4)	(4)
STH 53 Trempealeau Co.	MV3-SHRP	4260	0.026	31	0.0125	51,929	0.030	31	0.0175	104,375	0.064	31	0.0260	157,344	(4)	(4)	(4)
I-43 (NB) Waukesha Co.	HV3	1,520,672	(4)	(4)	(4)	2,324,023	0.057	28	0.0193	3,157,490	0.134	28	0.0290	4,022,201	0.078	28	0.0328
	SHRP MAC10	1,520,672	(4)	(4)	(4)	2,324,023	0.067	23	0.0179	3,157,490	0.133	23	0.0194	4,022,201	0.110	23	0.0257
	SMA-F1	1,520,672	(4)	(4)	(4)	2,324,023	0.069	29	0.0231	3,157,490	0.116	29	0.0182	4,022,201	0.125	29	0.0232
	SMA-F2	1,520,672	(4)	(4)	(4)	2,324,023	0.060	30	0.0165	3,157,490	0.125	30	0.0213	4,022,201	0.123	30	0.0289
	SMA-P1	1,520,672	(4)	(4)	(4)	2,324,023	0.061	30	0.0153	3,157,490	0.103	30	0.0174	4,022,201	0.093	30	0.0255
	SHRP-X	1,520,672	(4)	(4)	(4)	2,324,023	0.056	20	0.0161	3,157,490	0.094	20	0.0235	4,022,201	0.093	20	0.0265

(1) Overall average rut depth in right wheel path, inches.
(2) Number of reported 100 foot increments within test section.
(3) Standard deviation of rut depth measurements, inches.
(4) Rut depth data unavailable.

Table 4-1: Summary of Field Rutting Measurements (Cont.)

Project Location	Mix Type	1995				1996				1997				1998			
		ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)	ESAL	Rut (1)	n (2)	σ (3)
I-43 (SB) Waukesha Co.	HV3	1,520,672	(4)	(4)	(4)	2,324,023	0.066	29	0.0161	3,157,490	0.074	28	0.0113	4,022,201	0.072	29	0.0308
	MAC10	1,520,672	(4)	(4)	(4)	2,324,023	0.070	24	0.0112	3,157,490	0.090	24	0.0130	4,022,201	0.083	24	0.0227
	SMA-E1	1,520,672	(4)	(4)	(4)	2,324,023	0.059	28	0.0089	3,157,490	0.115	28	0.0307	4,022,201	0.136	28	0.0340
	SMA-E2	1,520,672	(4)	(4)	(4)	2,324,023	0.055	30	0.0155	3,157,490	0.080	30	0.0400	4,022,201	0.094	30	0.0356
	SMA-P2	1,520,672	(4)	(4)	(4)	2,324,023	0.066	30	0.0148	3,157,490	0.104	30	0.0171	4,022,201	0.097	30	0.0451
	SHRP-X	1,520,672	(4)	(4)	(4)	2,324,023	0.071	20	0.0110	3,157,490	0.101	20	0.0165	4,022,201	0.086	20	0.0350

(1) Overall average rut depth in right wheel path, inches.
(2) Number of reported 100 foot increments within test section.
(3) Standard deviation of rut depth measurements, inches.
(4) Rut depth data unavailable.

5.0 ANALYSIS OF COLLECTED DATA

The collected field and laboratory rutting data was analyzed to 1) determine the statistical significance of differences in mean rutting observed within each test section, and 2) to determine if a correlation could be developed between GaLWT test results and field performance.

5.1 Statistical Analysis of Field Rutting Data

The primary objective of the statistical analysis of field rutting data was to differentiate HMA mix designs based on accumulated rutting as a function of traffic loadings. It was initially intended to combine all collected field data (i.e., all survey dates and project site combinations) to develop general rutting models. A review of collected field data indicates numerous data anomalies resulting in erratic rut depth accumulations. Figure 5-1 illustrates this case for the five test sections constructed with SMA-E2 mix designs. As shown, the data collected on USH 45 shows a significant increase in rutting in 1996 (central ESAL value for each test section) followed by an equally significant drop in 1997. Furthermore, the 1997 data indicates lower average rut depths than the 1995 data (endpoint ESAL values for each test section). These atypical trends, which were observed at many project locations, may be associated with equipment modifications completed in 1996, resolution of rut depth measurements, and/or vehicle placement during measurements. Regardless of the cause, it was felt that aggregation of all collected data would be unjustified and that site specific comparisons of rutting data, by year, would be more appropriate. This strategy would also isolate two main variables, traffic and climate.

Based on the above premise, a paired-t analysis was conducted for each project site using field rutting data collected during each survey year. The average rut depth for each 100 foot sample segment within each test section was considered as one observation. The number of observations (number of 100 foot sample segments), the overall average rut depth, and the standard deviation of sample segment rut depths were determined for each test section as shown previously in Table 4-1. These values were used to compute the t-value associated with the hypothesis test that the sample means of two separate sections are statistically equal at the 95% confidence level. Where computed t-values exceed those established based on the degrees of freedom for the paired analysis, i.e., $|t| > t_{\alpha,(n1+n2-2)}$, it is concluded that the overall sample means are statistically different.

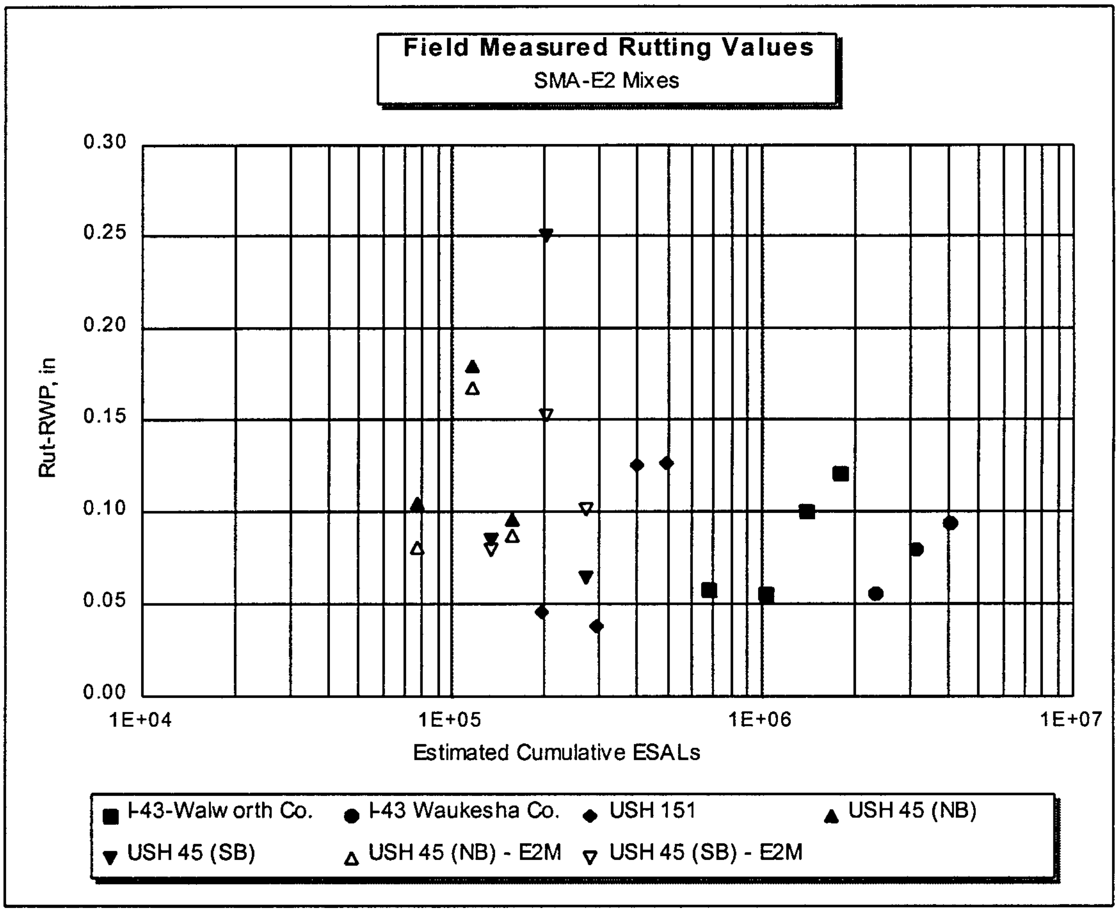


Figure 5-1: Field Rutting Measurements for SMA-E2 Mix Designs

Table 5-1 provides the results of this paired-t analysis. Tabular notations indicate those sections with overall average measured rutting values that are statistically greater than the referenced section. These results are comparative to an analysis of variance (ANOVA) with the advantage that specific sections with greater rutting can easily be identified.

Table 5-1: Paired-t Analysis Results

Reference Section	Test Sections with Significantly Greater Rutting (95% Confidence Level)			
	1995 Data	**1996 Data**	**1997 Data**	**1998 Data**
USH 45 (SB) - Oneida/Vilas County				
HV3	none	F 1	P1, F2, E1, E2M	n.a.
SMA-F 1	none	none	E1, E2M	n.a.
SMA-F 2	none	none	none	n.a.
SMA-P 1	none	none	E1, E2M	n.a.
SMA-P 2	P 1, E 1, E 2	F1	E1, E2M	n.a.
SMA-E 1	none	none	none	n.a.
SMA-E 2	none	none	E1, E2M	n.a.
SMA-E 2 M	none	All	none	n.a.
USH 45 (NB) - Oneida/Vilas County				
HV3	F2	P1, F2, E1	E1	n.a.
SMA-F 1	P2, F2, E2	P1, F2, E1, E2M	P1, F2, E1, E2, E2M	n.a.
SMA-F 2	E2M	E2	none	n.a.
SMA-P 1	none	none	none	n.a.
SMA-P 2	none	F2, E1	none	n.a.
SMA-E 1	F2	none	none	n.a.
SMA-E 2	none	E1	none	n.a.
SMA-E 2 M	F2	E1,F2	none	n.a.
STH 73 Columbia County				
MV3-P (1)		MV3 - R	MV3 - R	n.a.
MV3-R (2)	MV3-P			n.a.

(1) MV3-P = Base PCC w/ joint patching
(2) MV3-R = Base PCC rubblized before overlay

Table 5-1: Paired-t Analysis Results (Cont.)

Reference Section	Test Sections with Significantly Greater Rutting (95% Confidence Level)			
	1995 Data	1996 Data	1997 Data	1998 Data
USH 151 - Grant/Lafayette County				
HV3	none	E1	F1	F1, F2, P1, P2, E2
SMA-F 1	none	none	none	none
SMA-F 2	none	none	none	none
SMA-P 1	none	none	E1, F1, E2	none
SMA-P 2	none	none	E1, F1, E2	none
SMA-E 1	none	none	F1, E2	none
SMA-E 2	none	E1, P1, F2	none	none
I - 43 (NB) Walworth County				
SMA-F 1	none	none	none	P1, HV3
SMA-P 1	none	F1	F1	HV3
SMA-F 2	none	F1	none	P1, HV3
SMA-P 2	none	none	none	P1, HV3
HV 3	none	none	none	none
I-43 (SB) Walworth County				
SMA-E 1	none	none	none	E2
SMA-E 2	none	none	none	none
HV 3	none	none	none	E2
HV-Mac 10	none	none	none	E1, E2, HV3
I - 94 Waukesha County				
SMA(E)	none	none	none	none
A3	none	none	none	none

Table 5-1: Paired-t Analysis Results (Cont.)

Reference Section	Test Sections with Significantly Greater Rutting (95% Confidence Level)			
	1995 Data	***1996 Data***	***1997 Data***	***1998 Data***
I-43 Waukesha County (NB)				
HV3	n.a.	none	none	MAC10, F1, F2
SHRP MAC10	n.a.	none	none	none
SMA-F 1	n.a.	none	none	none
SMA-F 2	n.a.	none	none	none
SMA- P 1	n.a.	none	HV3, MAC10, F2	F1, F2
SHRP-X	n.a.	none	HV3, MAC10, F2	F1
I-43 Waukesha County (SB)				
HV3	n.a.	none	MAC10, SHRP-X	E1
SHRP MAC10	n.a.	none	none	E1
SMA-E 1	n.a.	MAC 10, SHRP-X	HV3, MAC10, E2, SHRP-X	none
SMA-E 2	n.a.	none	none	E1
SMA-P 2	n.a.	none	HV3, MAC10, E2, SHRP-X	none
SHRP-X	n.a.	none	none	E1

5.2 Discussion of Paired-t Analysis

To clarify the results presented in Table 5-1, each project location will be discussed separately followed by an overall discussion of results. It should be noted that project locations at USH 51, USH 53, STH 67, I-894, I-43/894 and STH 100 did not contain variable mix designs and thus no paired-t analysis could be conducted. Rutting results from these sections are included in the correlation analysis between the GaLWT and field observations presented in Section 5.3.

5.2.1 USH 45 (SB) - Oneida/Vilas Co.

The collected field data indicates variable results based on the year of testing. The 1995 data indicates section P2 has the best performance with sections P1, E1, and E2 performing the worst. The 1996 data indicates section E2M (milled AC surface) has the best performance and section F1 the worst. The 1997 data indicates sections E1 and E2M are the worst performing and the HV3 the best.

5.2.2 USH 45 (NB) - Oneida/Vilas Co.

The 1995 data indicates section F2, which had the greatest rutting, was performing significantly poorer than sections HV3, F1, E1, and E2M. The 1996 data also indicates section F2 had the worst performance, being significantly poorer than sections HV3, P2, and E2M. Section E1 had the second worst performance, being significantly poorer than sections HV3, F1, P2, E2, and E2M. The 1997 data indicates section F1 had the best performance, being significantly better than sections P1, F2, E1, E2, and E2M.

5.2.3 STH 73 - Columbia Co.

The 1995 data indicates the MV3 section constructed over the patched PCC pavement is performing significantly poorer then the MV3 section constructed over the rubblized PCC pavement. This performance analysis is reversed for the 1996 and 1997 data.

5.2.4 USH 151 - Grant/Lafayette Co.

The 1995 data shows no significant variations between sections. In 1996, the best performing E2 mix had significantly better performance that sections E1, P1 and F2. The Control HV3 mix also had significantly better performance than the E1 section. In 1997, sections F1 and E2 had the worst performance, being significantly poorer than sections HV3, P1, P2, and E1. In 1998, the HV3 mix had the best performance, being significantly better than all but the E1 section.

5.2.5 I-43 (NB) - Walworth Co.

The 1995 - 1997 survey only includes data from sections F1, E1 and P1. No significant variations between sections was noted in 1995. In 1996, section F1 had the worst performance, being significantly poorer than sections P1 and P2. In 1997, section F1 again had the worst performance, being significantly poorer than only section P1. The 1998 data, which includes all sections, showed the HV3 section to have the worst performance, being significantly poorer than all other sections. Section P1 had the second worst performance, being significantly poorer than the remaining F1, F2, and P2 sections.

5.2.6 I-43 (SB) - Walworth Co.

The 1995 - 1997 survey only includes data from sections HV3 and E2. No significant variations between sections was noted between 1995 - 1997. The 1998 data, which includes all sections, indicates the HV MAC 10 section to be performing the best, having significantly less rutting than all other sections. Section E2 had the second worst performance, being significantly poorer than the remaining HV3 and E1 sections. No significant differences between the HV3 and E1 sections were noted.

5.2.7 I-94 - Waukesha Co.

No significant differences were noted between the SMA(E) and A3 sections for any of the 1995 - 1998 survey years.

5.2.8 I-43 (NB) - Waukesha Co.

No 1995 survey data was available. The 1996 data showed no significant difference in test section performance. The 1997 data indicated the HV3, MAC10 and F2 sections to be performing significantly poorer than the P1 and SHRP-X sections. The 1998 data indicates section F1 is the worst performing, being significantly poorer than section HV3, P1 and SHRP-X. The second worst performing section was section F2, being significantly poorer than sections HV3 and P1. The next poorer section was the MAC10 section, having significantly poorer performance than the best performing HV3 section.

5.2.9 I-43 (SB) - Waukesha Co.

No 1995 performance data was available. The 1996 data indicated that section E1 had the best performance, being significantly better than sections MAC10 and SHRP-X. The 1997 data indicated the SHRP-X and MAC10 sections had the worst performance, being significantly poorer than all but the E2 section. Sections E1 and P2 were performing significantly better than all other sections. In 1998, the performance trends reversed, with the worst performing section E1 being significantly poorer than all sections except the next worst performing section P2.

5.2.10 General Performance Trends

Appendix A provides plots of field rutting data collected between 1995 and 1998 for each mix design. Zero-intercept log-linear performance equations, developed from collected rut data after exclusion of data outliers, are provided in Table 5-2. The zero-intercept equations are of the form:

$$RD = A * Log(ESAL)$$

where: RD = rut depth in right wheel path, inches
A = regression constant
ESAL = estimated cumulative ESAL value

As can be seen in Table 5-2, all zero-intercept equations have poor correlation statistics (i.e., $R^2 < 0.4$) indicating this simple model form will not prove useful for predicting field ruttting behavior.

Table 5-2: Rutting Performance Equations
Rut Depth = A* Log (ESAL)

Mix Type	Location	A	R^2
F1	I-43 Walw	0.014	.092
F1	I-43 Wauk	0.016	.117
F1	USH 151	0.017	.132
F1	All (1)	0.016	.104
F2	I-43 Walw	0.013	.075
F2	I-43 Wauk	0.016	.088
F2	USH151	0.017	.159
F2	All (1)	0.016	.036
P1	I-43 Walw	0.013	.079
P1	I-43 Wauk	0.013	.106
P1	USH151	0.016	.171
P1	All (1)	0.014	.044
P2	I-43 Walw	(2)	(2)
P2	I-43 Wauk	0.014	.124
P2	USH151	0.016	.137
P2	All (1)	0.014	.066
E1	I-43 Walw	(2)	(2)
E1	I-43 Wauk	0.016	.092
E1	USH151	0.016	.175
E1	All (1)	0.016	.180
E2	I-43 Walw	0.014	.133
E2	I-43 Wauk	0.012	.137
E2	USH151	0.015	.091
E2	All (1)	0.014	.044

(1) Excludes USH 45 data
(2) Insufficient data for analysis

Table 5-2: Rutting Performance Equations (Cont.)
Rut Depth = A* Log (ESAL)

Mix Type	Location	A	R^2
HV3	I-43 Walw	0.014	.319
HV3	I-43 Wauk	0.011	.381
HV3	USH 151	0.011	.288
HV3	USH 51	0.010	.100
HV3	STH 67	0.024	.308
HV3	I94	0.012	.058
HV3	All (1)	0.013	-.081
SMA	Ryan Rd	0.013	.168
SMA	I 894	0.012	.345
SMA	I43 MAC10	0.014	.060
SMA	143 SHRP-X	0.012	.141
SMA	All	0.013	.146
MV3	STH73-P	0.018	.147
MV3	STH73-R	0.018	.123
MV3	All	0.018	.133
SHRP	STH 53	0.009	.367

1) Excludes USH 45 data

Table 5-3 provides unconstrained log-linear performance equations, again developed from collected rut data after exclusion of data outliers. The unconstrained equations are of the form:

$$RD = A * \text{Log}(ESAL) + B$$

where: RD = rut depth in right wheel path, inches
A,B = regression constants
ESAL = estimated cumulative ESAL value

Table 5-3: Unconstrained Rutting Performance Equations
Rut Depth = A* Log (ESAL) + B

Mix Type	Location	A	B	R^2	Delay(1)
F1	I-43 Walw	0.290	-1.657	.984	5.1E5
F1	I-43 Wauk	0.240	-1.456	.909	1.1E6
F1	USH151	0.215	-1.091	.853	1.2E5
F1	All (3)	0.029	-0.079	.131	5.3E2
F2	I-43 Walw	0.338	-1.950	.974	5.8E5
F2	I-43 Wauk	0.274	-1.677	.784	1.3E6
F2	USH151	0.194	-0.979	.956	1.1E5
F2	All (3)	0.031	-0.094	0.134	1.0E3
P1	I-43 Walw	0.318	-1.830	.987	5.7E5
P1	I-43 Wauk	0.142	-0.837	.599	7.7E5
P1	USH151	0.156	-0.772	.866	8.7E4
P1	All (3)	0.015	-0.003	0.044	1.6E0
P2	I-43 Walw	(2)	(2)	(2)	(2)
P2	I-43 Wauk	0.137	-0.799	.653	6.9E5
P2	USH151	0.182	-0.916	.833	1.1E5
P2	All (3)	0.013	0.010	0.067	0
E1	I-43 Walw	(2)	(2)	(2)	(2)
E1	I-43 Wauk	0.327	-2.022	.965	1.5E6
E1	USH151	0.173	-0.855	1.000	9.0E4
E1	All (3)	0.024	-0.053	0.206	1.5E2
E2	I-43 Walw	0.159	-0.879	.800	3.4E5
E2	I-43 Wauk	0.165	-0.993	.991	1.1E6
E2	USH151	0.234	-1.207	.724	1.4E5
E2	All (3)	0.016	-0.015	0.045	8.6E0

(1) Accumulated ESALs prior to rut initiation
(2) Insufficient data for analysis
(3) Excludes USH 45 Data

Table 5-3: Unconstrained Rutting Performance Equations (Cont.)

Rut Depth = A* Log (ESAL) + B

Mix	Location	A	B	R^2	Delay (1)
HV3	I-43 Walw	0.079	-0.398	.998	1.0E5
HV3	I-43 Wauk	0.027	-0.103	.587	7.0E3
HV3	USH 151	0.022	-0.060	.390	6.4E2
HV3	USH 51	(2)	(2)	(2)	(2)
HV3	STH 67	(2)	(2)	(2)	(2)
HV3	I94	0.251	-1.511	.613	1.0E6
HV3	All (3)	-0.003	0.096	.004	0
SMA	Ryan Rd	0.118	-0.636	.830	2.5E5
SMA	I 894	0.029	-0.106	.527	4.5E3
SMA	I43 MAC10	0.126	-0.729	.285	5.8E5
SMA	143 SHRP-X	0.112	-0.649	.678	6.0E5
SMA	All (3)	0.043	-0.192	.287	2.8E4
MV3	STH73-P	0.202	-0.928	.874	4.0E4
MV3	STH73-R	0.263	-1.239	.958	5.2E4
MV3	All	0.232	-1.083	.909	4.7E4
SHRP	STH 53	0.021	-0.054	.543	3.6E2

(1) Accumulated ESALs prior to rut initiation
(2) Insufficient data for analysis
(3) Excludes USH 45 Data

As shown in Table 5-3, the unconstrained log-linear model form provides significantly better correlations, with many site-specific models having R^2 values greater than 0.900. However, all models have negative intercept values (B) indicating a negative rut depth after the first ESAL application which is in obvious conflict with pavement behavior. From another viewpoint, the negative intercept values (B) can be combined with the positive slope values (A) to provide an indication of the cumulative applied ESAL values prior to the initiation of rutting. For this analysis method, the ESAL delay to rut development can be calculated as:

$$\text{Delay} = 10^{(-B/A)}$$

where: Delay = cumulative ESALs prior to rut initiation
B = regression constant (intercept)
A = regression constant (slope)

Calculated delay values are provided in Table 5-3 for each performance equation.

Figure 5-2 illustrates the goodness of fit for the zero-intercept and unconstrained log-linear performance for a representative pavement section, plotted with arithmetic ESAL scaling. As shown, the zero-intercept model form provides for proper zero-ESAL/zero-rut initiation but everywhere else the model poorly describes observed field behavior. Conversely, the unconstrained model form provides excellent agreement with field data as well as capturing the general trend of observed long-term field rut development.

Table 5-4 provides a relative ranking (1 = best) of field rutting performance for the three Southern Wisconsin test locations which included the full range of mix type variations. For these rankings, a smaller regression constant A (slope) indicates better rutting performance (i.e., slower rut depth accumulation with increasing ESALs). From this perspective, the standard HV3 mix design provides the best long-term rutting performance based on the collected field data.

It is also interesting to note that higher slope values are consistently paralleled with increased delay values. These increased delays, however, are not sufficient to offset the accelerated rut development indicated by the higher slope. This would indicate that projected long-term rutting would be higher for mix types with higher slope values. Figure 5-3 illustrates this point for selected mix types along I-43 in Waukesha County.

Table 5-4: Rutting Performance Rankings for Southern Wisconsin Locations
Rut Depth = A* Log (ESAL) + B

Mix Type	Relative Ranking	Project Location	Slope A	ESAL Delay(1)
HV3	1	I-43 Walw	0.079	1.0E5
E2	2	I-43 Walw	0.159	3.4E5
F1	3	I-43 Walw	0.290	5.1E5
P1	4	I-43 Walw	0.318	5.7E5
F2	5	I-43 Walw	0.338	5.8E5
P2		I-43 Walw	(2)	(2)
E1		I-43 Walw	(2)	(2)
HV3	1	I-43 Wauk	0.027	7.0E3
P2	2	I-43 Wauk	0.137	6.9E5
P1	3	I-43 Wauk	0.142	7.7E5
E2	4	I-43 Wauk	0.165	1.1E6
F1	5	I-43 Wauk	0.240	1.1E6
F2	6	I-43 Wauk	0.274	1.3E6
E1	7	I-43 Wauk	0.327	1.5E6
HV3	1	USH151	0.022	6.4E2
P1	2	USH151	0.156	8.7E4
E1	3	USH151	0.173	9.0E4
P2	4	USH151	0.182	1.1E5
F2	5	USH151	0.194	1.1E5
F1	6	USH151	0.215	1.2E5
E2	7	USH151	0.234	1.4E5

(1) Accumulated ESALs prior to rut initiation
(2) Insufficient data for analysis

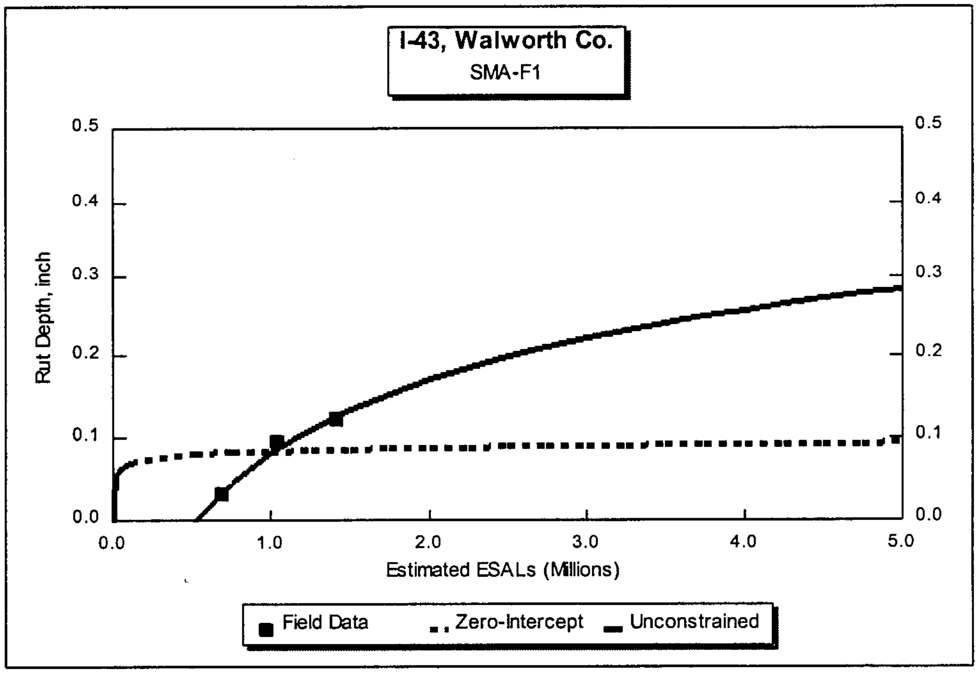


Figure 5-2: Comparison of Performance Model Trends

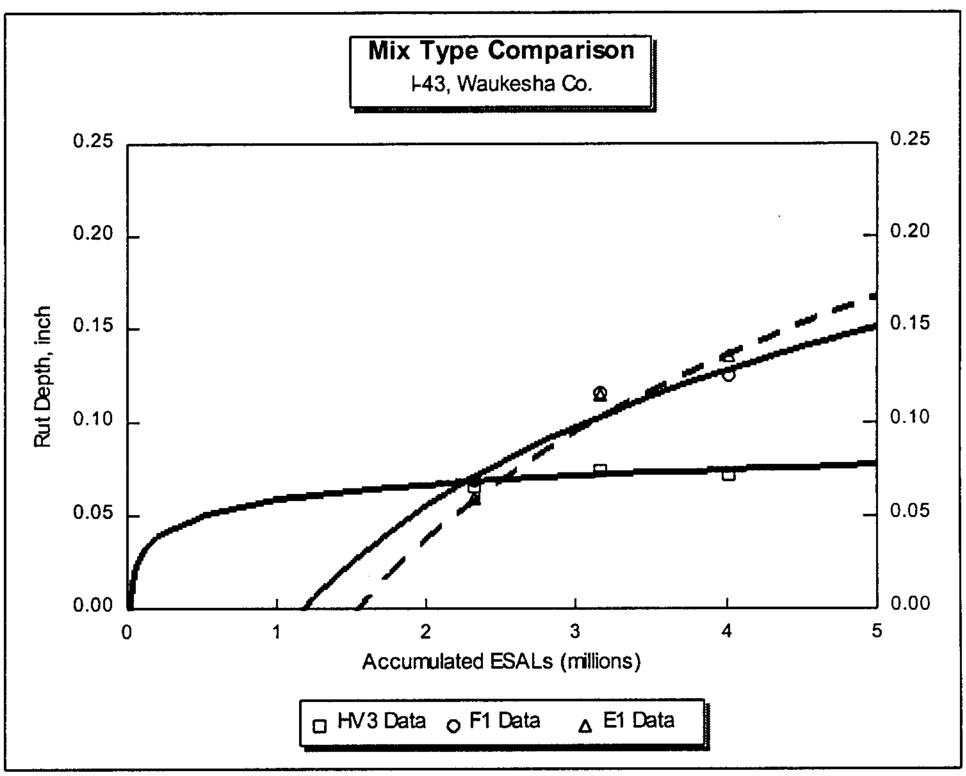


Figure 5-3: Comparison of Long-Term Rutting Performance

5.3 Correlations Between GaLWT and Field Rutting Measurements

A preliminary analysis of GaLWT test results and field performance was completed by ranking the various mix designs based on rut accumulations in the lab and in the field. The GaLWT test results are commonly used only as indicator values, separating rut susceptible mixes from non-rut susceptible mixes based on the rut depth measured after 8,000 load repetitions. A rut depth value of 0.3 inches (7.5 mm) was initially established as the threshold laboratory indicator value. Other States have developed modified threshold values based on research similar to that presented in this report.

Table 5-5 provides a relative ranking of test sections for the three project locations which contained variable mix designs and where lab samples were tested. Rankings are based on laboratory test results as well as field rutting performance measured during the most recent field survey at each site. For ranking purposes, the best performing mix was selected as having the least amount of measured rutting. Subsequent rankings indicate increased rut depth measurements. Laboratory-based rankings shown in brackets represent mixes with rut depths exceeding 0.3 inches, mixes which may be considered as rut susceptible based on original guidelines.

The data provided in Table 5-5 indicates general agreement between lab and field rankings for sections constructed along I-43 in Walworth Co. The lab results do, however, indicate significant differences between rankings for F1 and E2 mixes based on lab prepared and field obtained specimens. Test results for the lab prepared specimens are in better agreement with field observations. For sections constructed along USH 151 in Grant/Lafayette Co., lab results between lab prepared and field obtained specimens are in general agreement with slight shifts in relative rankings. Comparisons between field and lab rankings are erratic, with the best performing field mix (HV3) being the worst performing lab mix. For sections constructed along USH 45, comparisons between field and lab rankings are also erratic. Again, the better performing field mix (HV3) was the worst performing lab mix. Also, the best performing lab mix (E2) showed poor performance on the Northbound section. The remaining sections are generally ranked consistently between lab and field results.

Table 5-5: Relative Ranking of Mix Designs

Project Location	Test Result	Relative Ranking - Best to Worst (1)
I-43 Walworth Co.	Lab - Lab Prepared	F1 - F2 - P1 - [E2 - HV3] (E1, P2, HVMAC10 not tested)
	Lab - Field Obtained	E2 - F2 - P1 - [HV3 - F1] (E1, P2, HVMAC10 not tested)
	NB Field Measurements	F1 - F2 - P2 - P1 - HV3
	SB Field Measurements	HVMAC10 - E1 - HV3 - E2
USH 151 Grant/Lafayette Co.	Lab - Lab Prepared	P2 - P1 - F1 - E1 - F2 - HV3 (E2 not tested)
	Lab - Field Obtained	P1 - P2 - E1 - F1 - F2 (E2,HV3 not tested)
	Field Measurements	HV3 - E1 - P2 - P1 - E2 - F2 - F1
USH 45 Oneida/Vilas Co.	Lab - Lab Prepared	E2 - P2 - P1 - F1 - F2 - P1 - HV3 (E1 not tested)
	Lab - Field Obtained	(No field obtained specimens tested)
	NB Field Measurements	F1 - HV3 - P2 - P1 - E2M - E2 - F2 - E1
	SB Field Measurements	HV3 - E2 - P2 - F1 - P1 - F2 - E2M - E1

(1) Values in brackets [ ] indicate mixes with lab measured rutting exceeding 0.3 inches @ 8,000 reps

To develop numeric correlations between GaLWT rut accumulation and field rutting due to ESAL loadings, plots of GaLWT rut depths versus load repetitions were prepared for each test specimen. Using these plots, trend lines were constructed to represent laboratory rutting accumulation. Field measured rut depths at estimated accumulated ESAL values were then used as inputs to back-estimate the GaLWT load repetitions which produced rut depths of equal magnitude. Separate analyses were conducted for the laboratory prepared specimens and field obtained specimens, where available. Figures 5-4 and 5-5 illustrate comparative data, excluding atypical field rutting data, obtained from all project locations.

The benefit of analyses of this type is that both mix design and applied traffic can be excluded as variables. The only remaining variables are specimen type (i.e., lab prepared or field obtained) and field climate. It may be argued that GaLWT results on field obtained specimens, as compared to lab prepared, may provide better estimators of field rutting performance as the compacted density and aggregate structure represent in-place conditions. On the other hand, if GaLWT test results are to be used during the mix design process, lab prepared specimens are all that would be available. Compaction protocol (i.e., full-face repetitive, rolling-wheel, gyratory) affects aggregate structure and the full-face repetitive process used during lab testing may have produced specimens which are not fully representative of field conditions. Field climatic exposure also affects the rutting performance of an HMA pavement. Currently WisDOT does not differentiate mix design requirements based on project location within the State. The GaLWT protocol utilizes a test temperature of 105°F, which may be more representative of Southern U.S. locations. For comparative purposes, data points on Figures 5-4 and 5-5 indicate general location within the State. Separate identifiers were utilized for southern locations (USH 151, I-43, STH 67 and STH 100), central locations (USH 51), and northern locations (USH 45).

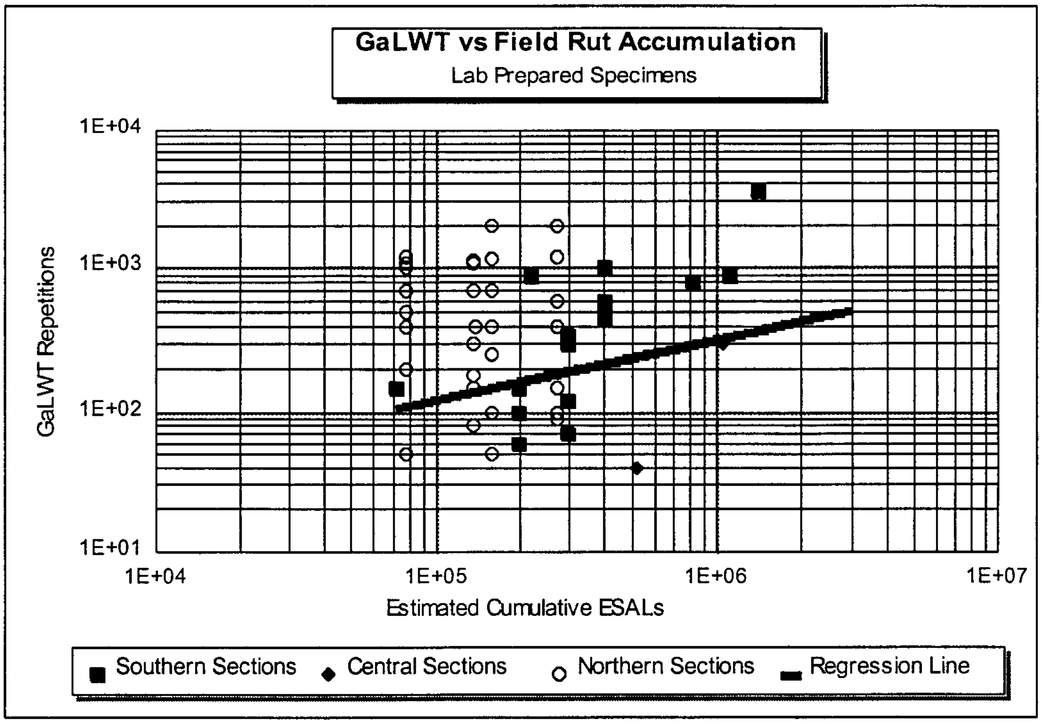


Figure 5-4: GaLWT Repetitions vs Cumulative ESALs for Lab Prepared Specimens

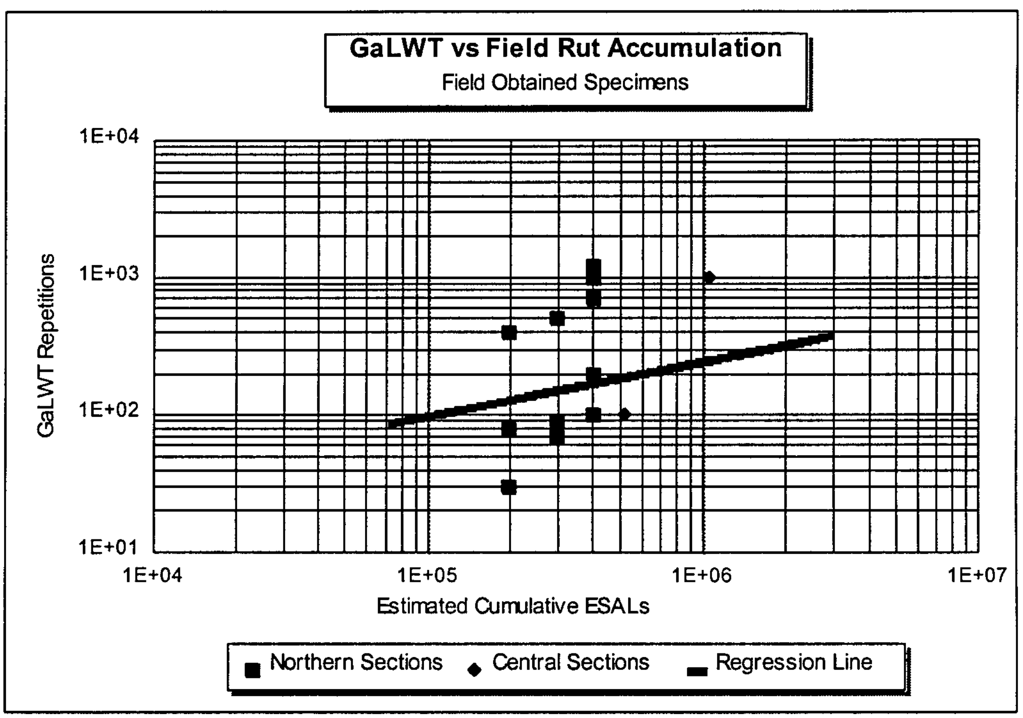


Figure 5-5: GaLWT Repetitions vs Cumulative ESALs for Field Obtained Specimens

5.4 Discussion of GaLWT Data Correlations

The results presented in Figures 5-4 and 5-5 indicate no general trend of data can be established. The broad scatter of the data precludes the development of a meaningful correlation equations. The results presented in Figure 5-5 show slightly better trends, with increased estimated ESALs generally indicating higher GaLWT load repetitions to equal rut depth. However, no field specimens were obtained from the Northern sections, eliminating those data points which added significantly to the scatter in Figure 5-4.

Using only the field data from the Northern and Central sections, the following regression equations were developed:

Lab Prepared Specimens:

$$\text{Log(GaLWT Reps)} = 0.42\ \text{Log(ESAL)} \qquad R^2 = 0.06$$

Field Obtained Specimens:

$$\text{Log(GaLWT Reps)} = 0.40\ \text{Log(ESAL)} \qquad R^2 = 0.06$$

The developed regression equations indicate no significant differences between field correlations with lab prepared and field obtained specimens. However, both equations have extremely small R^2 values, indicating significant errors are associated with GaLWT predictions for any given design ESAL value. As such, these equations have little practical use at this time for establishing target GaLWT load repetitions as a function of design traffic level.

6.0 SUMMARY AND CONCLUSIONS

This report has presented an analysis of laboratory and field rutting performance for a variety of HMA mix designs constructed throughout the State of Wisconsin. Laboratory testing using the Georgia Loaded Wheel Tester was conducted on specimens compacted in the lab as well as on specimens cut from the surface of the constructed pavements. Field rut measurements were taken at yearly intervals between 1995 and 1998 using two configurations of the WisDOT profiler.

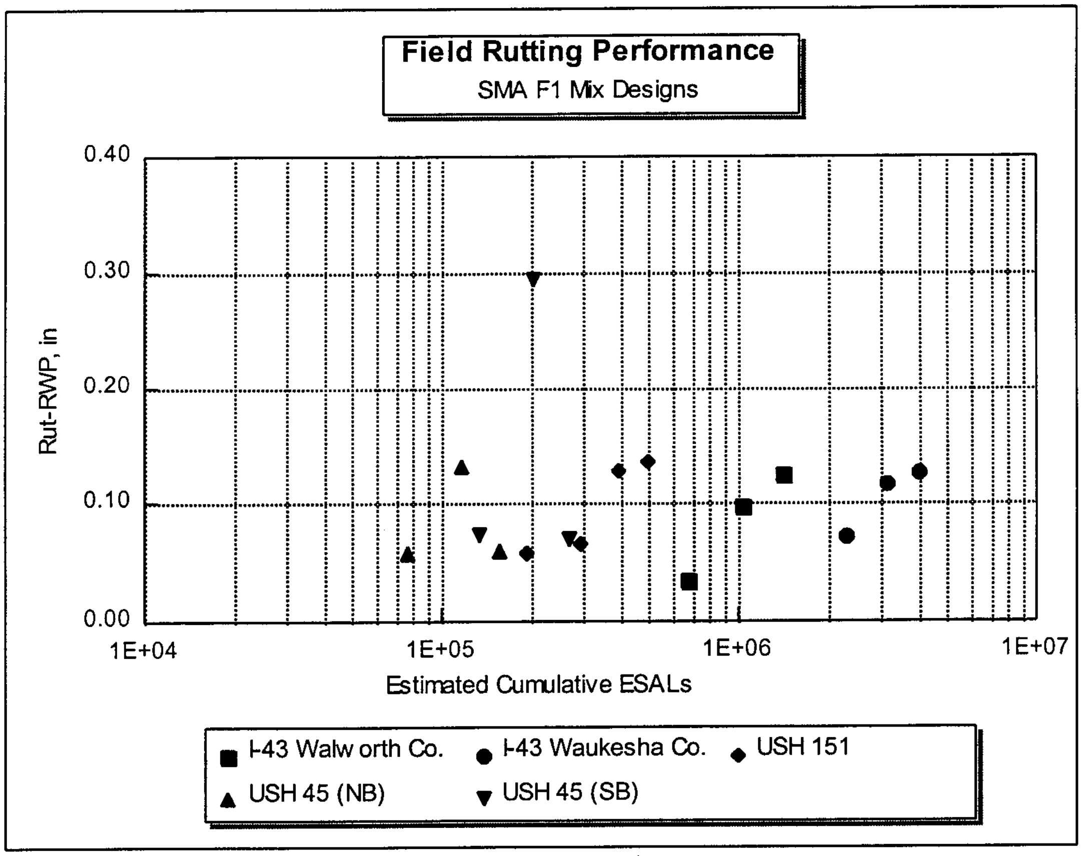
Based on field rutting data collected in Southern Wisconsin, mix designs incorporating the larger maximum aggreagte size (16 mm vs. 10 mm) are providing better long-term rutting resistance. Furthermore, the SMA mix designs investigated are not providing increased long-term rut resistance as compared to the standard WisDOT HV3 mix design.

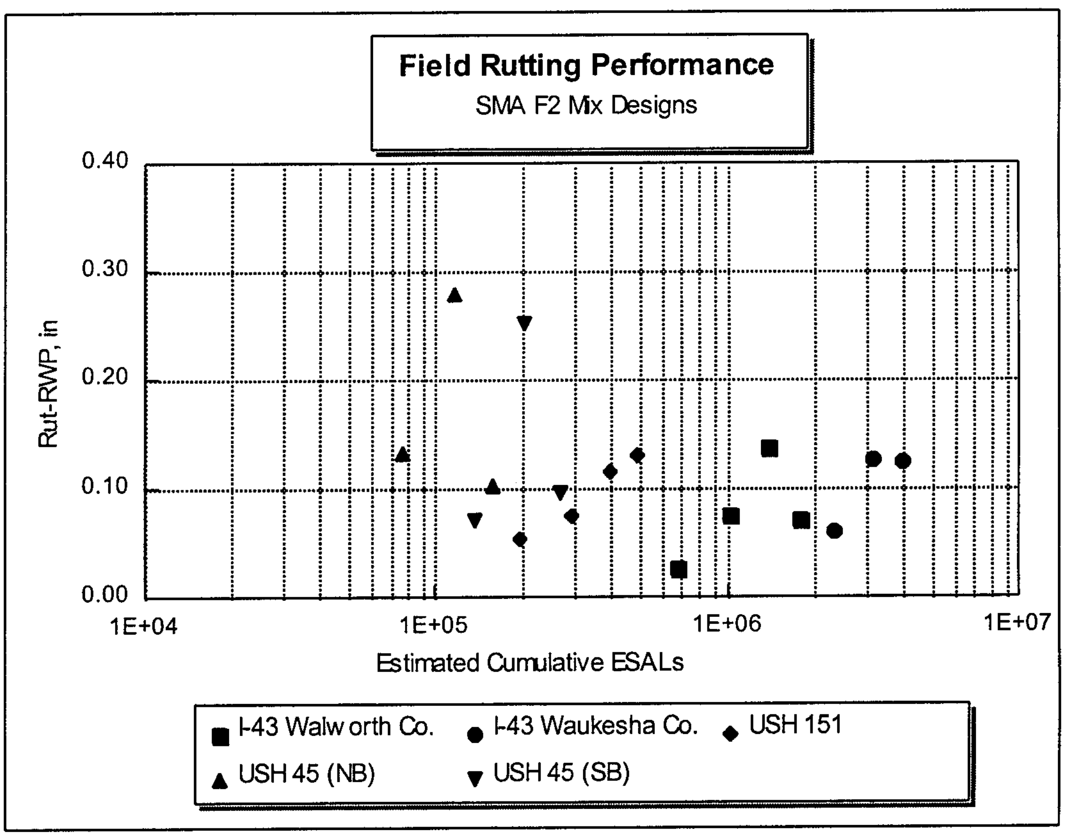
Site-specific relative rankings of the various mix designs were developed based on measured rut accumulations in the lab (lab prepared and field obtained specimens) as well from field rut measurements. Significant variations in lab and field performance were noted, producing inconsistent rankings for many of the mix designs. Direct comparisons of laboratory and field rutting development also yielded erratic results. The exact cause of this erratic behavior is unknown, but contributing factors may include variables in the laboratory test protocol used (i.e., compaction method, test temperature, load system) and the field measurement/analysis process, including equipment modifications completed in 1996, resolution of the rut measuring equipment, and/or vehicle placement during surveys.

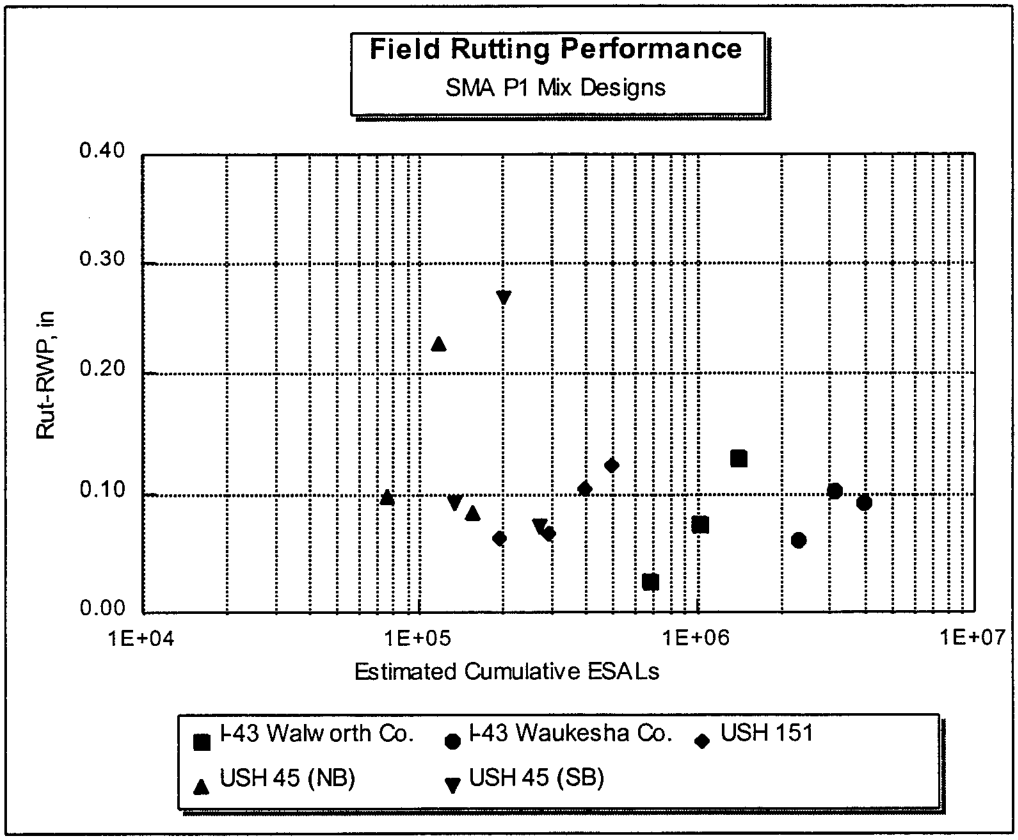
Regression equations for correlating laboratory rut depths to field rutting, for a range of cumulative ESAL values, were developed. However, the goodness of fit of these equations is poor and they may be of little practical use at this time. Regression equations were also developed for estimating field rutting based on cumulative ESAL values. Unconstrained log-linear performance models provided reasonably good site-specific correlation to observed field rutting performance for many of the project sites. However, erratic field rutting data precluded the development of general field performance equations that can be globally applied across the State. It may be possible to develop more meaningful general predictive equations using a more direct measure of field rut depths (i.e, straight edge, stringline, manual transverse tracing) at each project site. However, it is unclear at this time if these measures would reduce the data scatter to the point where these general equations would be of practical use.

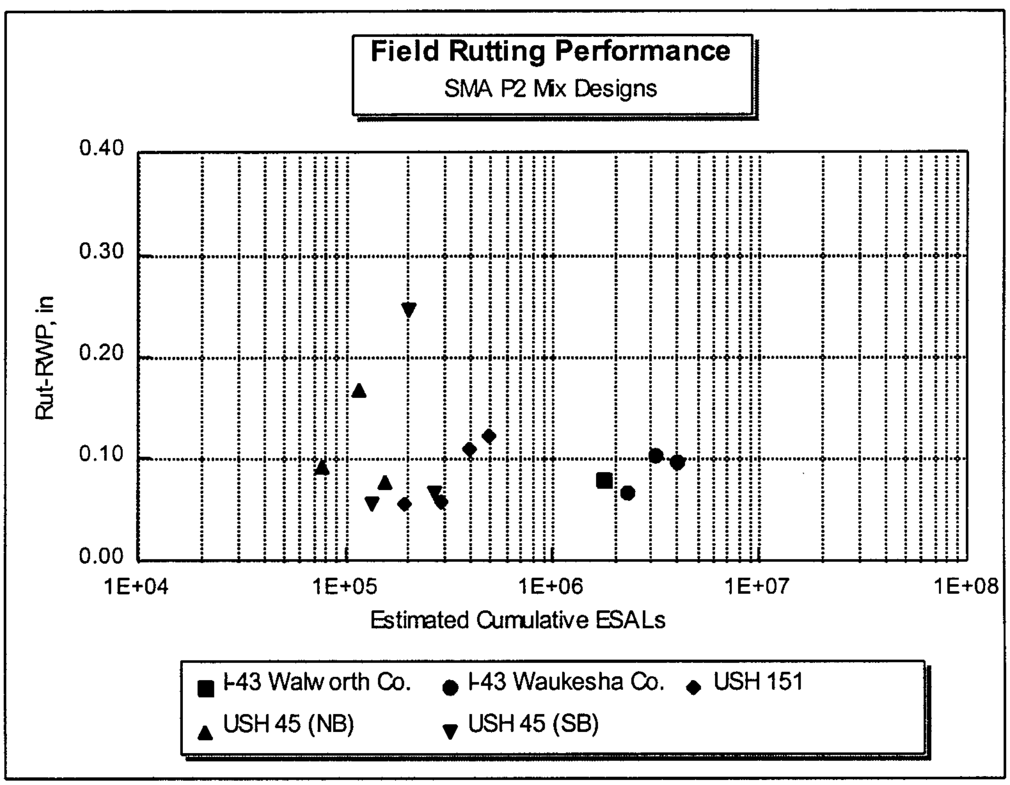
APPENDIX A

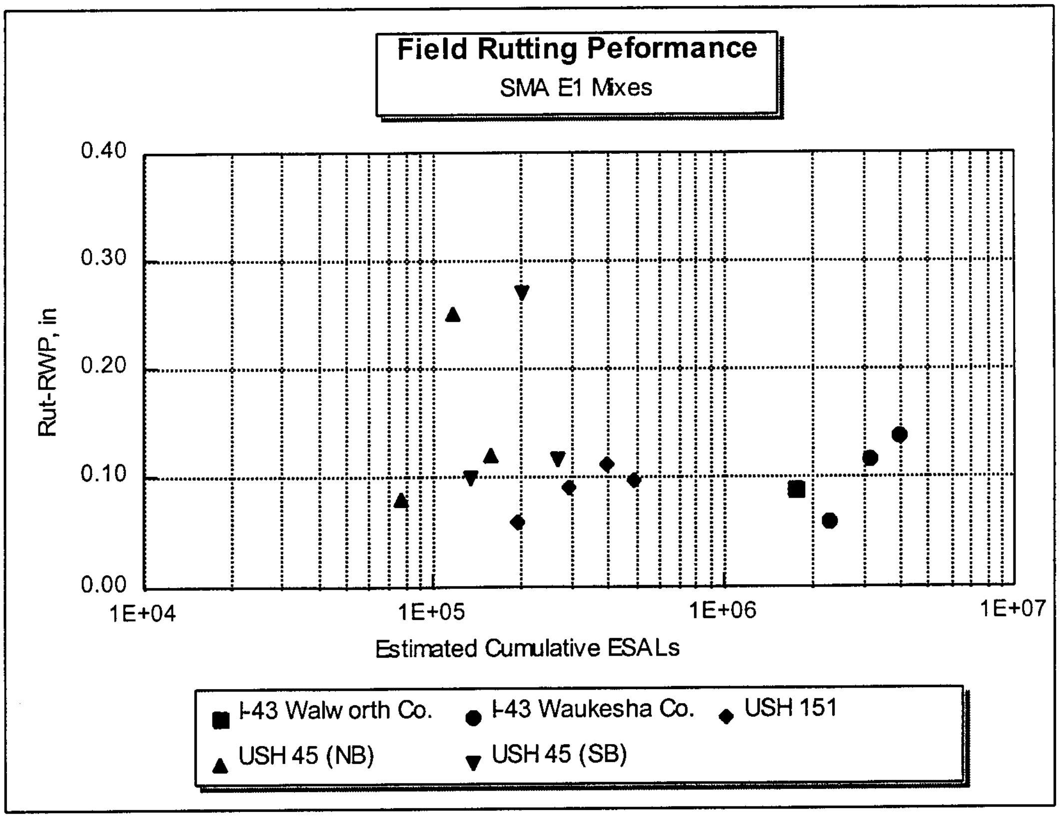
FIELD PERFORMANCE PLOTS

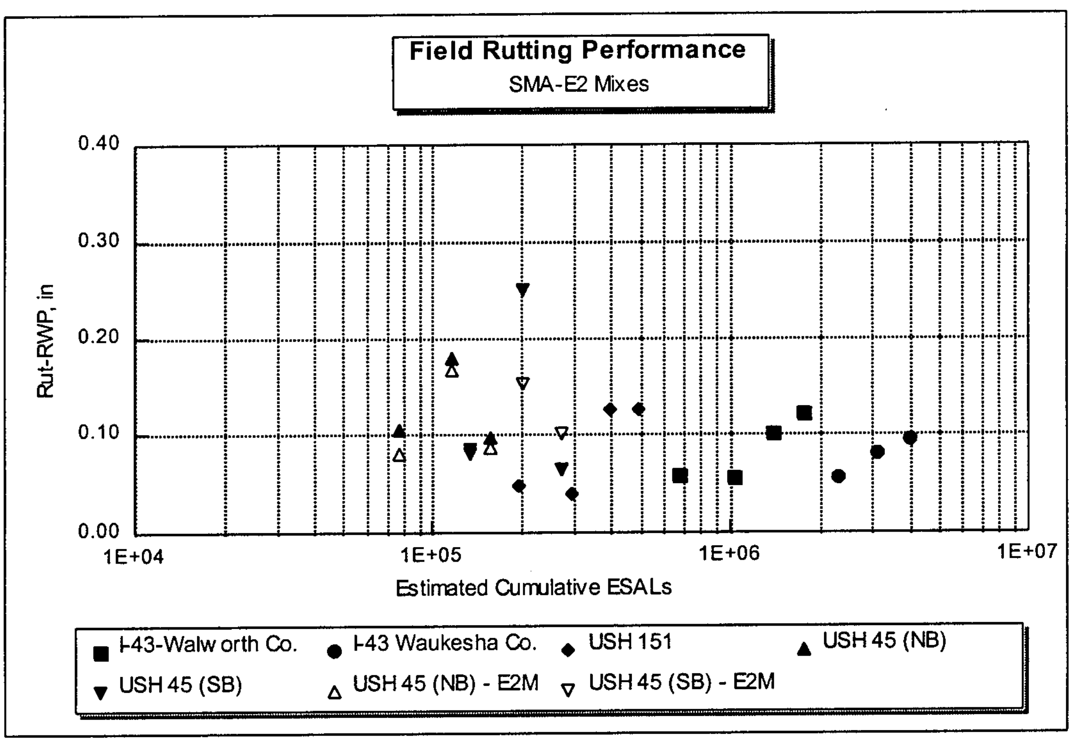

Field Rutting Performance
SMA F1 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43 Walworth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)

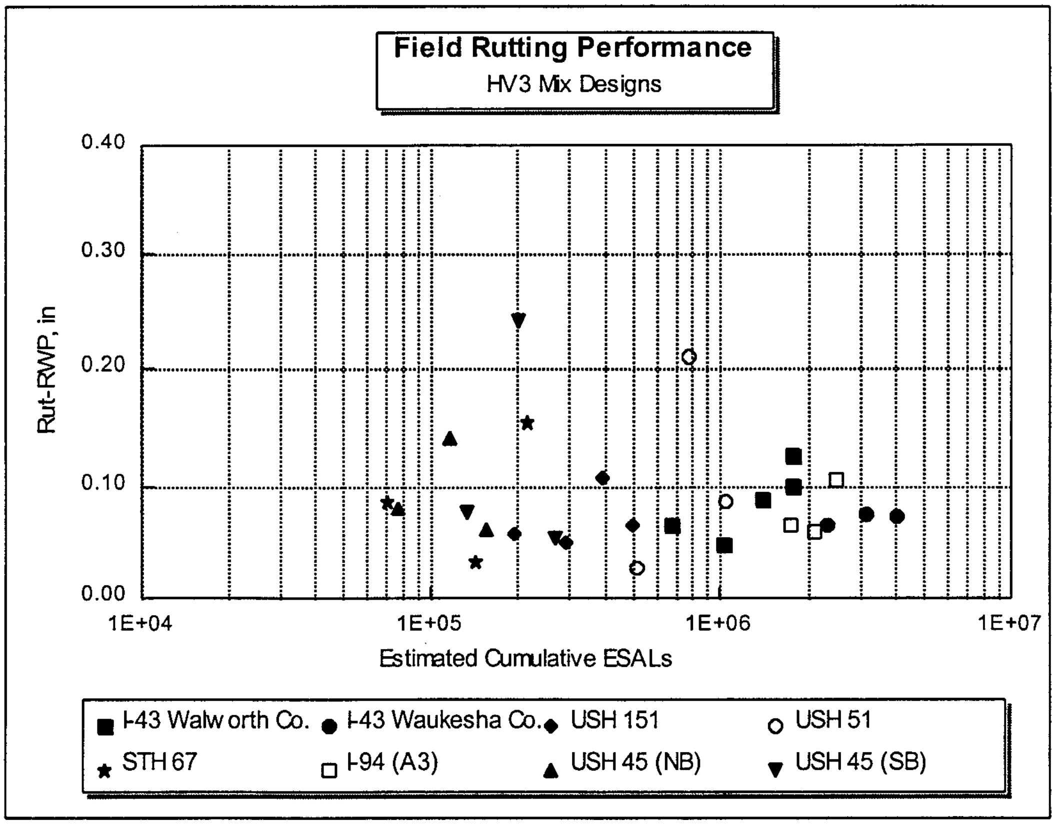

Field Rutting Performance
SMA F2 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43 Walworth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)


Field Rutting Performance
SMA P1 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43 Walworth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)

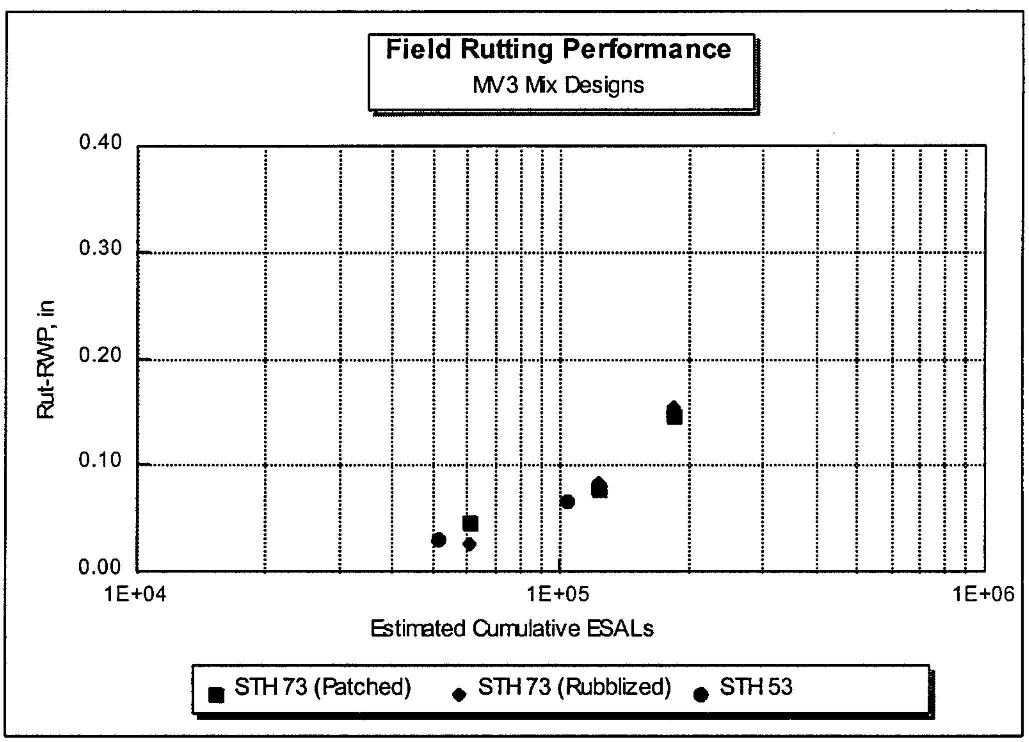

Field Rutting Performance
SMA P2 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
1E+08
Estimated Cumulative ESALs
I-43 Walworth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)


Field Rutting Peformance
SMA E1 Mixes
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43 Walw orth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)

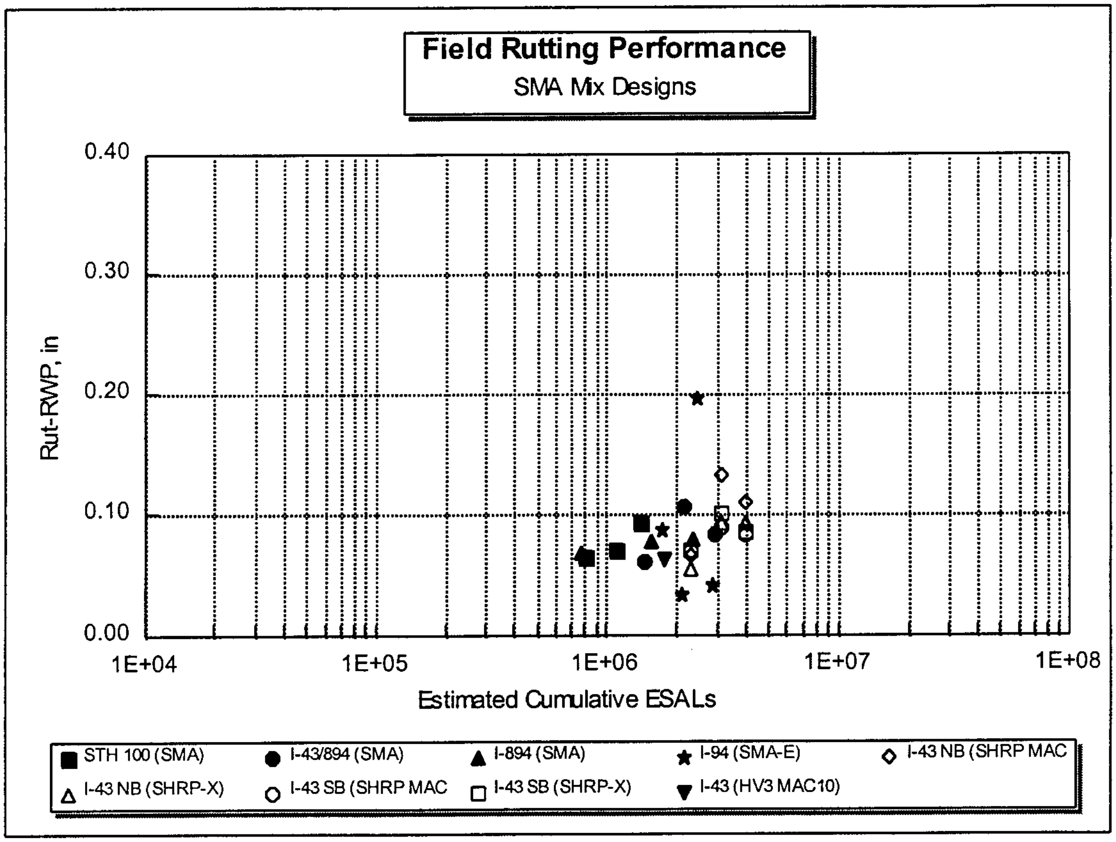

Field Rutting Performance
SMA-E2 Mixes
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43-Walw orth Co.
I-43 Waukesha Co.
USH 151
USH 45 (NB)
USH 45 (SB)
USH 45 (NB) - E2M
USH 45 (SB) - E2M



Field Rutting Performance
HV3 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
1E+07
Estimated Cumulative ESALs
I-43 Walworth Co.
I-43 Waukesha Co.
USH 151
USH 51
STH 67
I-94 (A3)
USH 45 (NB)
USH 45 (SB)



Field Rutting Performance
MV3 Mix Designs
0.40
0.30
0.20
0.10
0.00
Rut-RWP, in
1E+04
1E+05
1E+06
Estimated Cumulative ESALs
STH 73 (Patched)
STH 73 (Rubblized)
STH 53



Field Rutting Performance
SMA Mix Designs
Rut-RWP, in
0.40
0.30
0.20
0.10
0.00
1E+04
1E+05
1E+06
1E+07
1E+08
Estimated Cumulative ESALs
STH 100 (SMA)
I-43/894 (SMA)
I-894 (SMA)
I-94 (SMA-E)
I-43 NB (SHRP MAC
I-43 NB (SHRP-X)
I-43 SB (SHRP MAC
I-43 SB (SHRP-X)
I-43 (HV3 MAC10)